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High-Performance Laboratory Fume Hood Field Test at the University of California, San Francisco

Final Report for Pacific Gas and Electric Company

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SYNOPSIS

Fume hoods have long been used to protect workers from breathing harmful gases and particles, and are ubiquitous in pharmaceutical and biotechnology facilities, industrial shops, medical testing labs, private and university research labs, and high school chemistry labs. Fume hoods are box-like structures often mounted at tabletop level with a movable window-like front called a sash. They capture, contain and exhaust hazardous fumes, which are drawn out of the hood by fans.

Highlighting important systems-level factors, hoods require large amounts of air flow that tend to drive size and first cost of central heating, ventilating and air-conditioning (HVAC) systems. As a result, fume hoods are a major factor in making a typical facility in which they are used four- to five-times more energy intensive than typical commercial buildings. A typical hood consumes more energy than an average house. With as many as one million hoods in use in the U.S., aggregate energy use and savings potential is significant. This is especially so in California, with its extensive high-tech industrial base, where we estimate a savings potential of up to 200 megawatts of electrical generating capacity or $82 million annually.

Further amplifying the need to improve fume hood design, recent research shows that increasing the amount and rate of airflow (and, consequently, energy use) does not tend to improve containment. Instead, errant eddy currents and vortexes can be induced as air flows around workers and into the hood, reducing containment effectiveness and compromising safety, while boosting energy costs.

Existing approaches for saving energy in fume hoods are complicated and costly to implement, and do not address worker safety issues inherent in traditional fume hood design. Innovation is hampered by various barriers stemming from existing fume hood testing/rating procedures, entrenched industry practices, and ambiguous and contradictory guidance on safe levels of airflow.

To address the shortcomings of existing approaches and to promote innovation in the marketplace, Lawrence Berkeley National Laboratory has developed and patented a promising new technology—The Berkeley Hood—which uses a "push-pull" approach to contain fumes and move air. Small supply fans located at the top and bottom of the hood's face push air into the hood and into the user's breathing zone, setting up a protective "air divider" at the hood opening. Consequently, the hood's exhaust fan can be operated at a much lower flow rate. Because less air is flowing through the hood, the building's environmental conditioning system can be "downsized", saving both energy and initial costs of construction.

A series of field trials have increased understanding of the Berkeley Hood's operability under actual working conditions in functioning laboratories. PG&E has sponsored a field test at the University of California, San Francisco Medical Center, where the Berkeley Hood has performed quite well and, in some cases, exceeded expectations. The hood contained the proxies for pollutants (test smoke and tracer gas) under all conditions down to 33 percent flow compared to a standard hood. By comparison, the pre-existing standard hood failed CAL/OSHA and NIH safety tests even at full flows. A post-occupancy evaluation revealed a high level of user satisfaction, and industry has considerable interest in commercializing the technology.

EXECUTIVE SUMMARY

Laboratory Fume Hoods—Critical But Costly

Fume hoods have long been used to protect workers from breathing harmful gases and particles by capturing hazardous airborne materials created in laboratories, manufacturing facilities, and other settings (Fig ES-1). These box-like structures offer users protection with a movable, window-like front “face” called a sash. Fans draw fumes out of the tops of the hoods. With approximately one million hoods in use in the U.S., aggregate energy use and savings potential is significant.

Figure ES-1. Standard laboratory hood in use. Courtesy Labconco Corp.

Conventional fume hoods rely solely on pulling air through the hood's open sash from the laboratory, around the worker, and through the hood workspace.

The generally accepted “face velocity” is around 100 feet per minute, depending on hazard level. Interestingly, recent research shows that increasing face velocity (and, consequently, air volume and energy use) does not tend to improve containment. Instead, errant eddy currents and vortexes are induced in the hood and around hood users as air flows into the hood, reducing containment effectiveness and compromising worker safety (Figure ES-2).

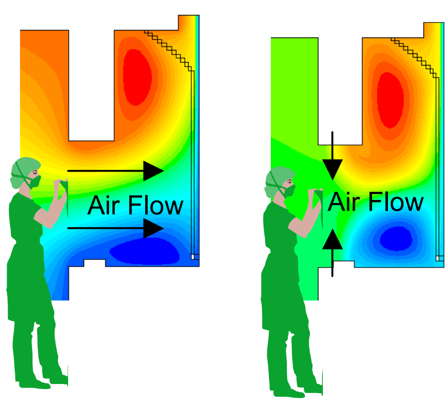

Figure ES-2. CFD Modeling. Standard fume hood (left) and Berkeley Hood (right), with smaller vortices (red and blue circular areas) and the air divider isolating interior and exterior air flows.

Typical fume hoods exhaust large volumes of air at great expense. Furthermore, the energy to filter, move, cool or heat, and in some cases scrub (clean) this air is one of the largest loads in most facilities and tends to drive the sizing (first cost) and energy use of the central heating, ventilating and air-conditioning systems in the buildings in which the hoods are located. Fume hoods are a major factor in making a typical laboratory four- to five-times more energy intensive than a typical commercial building. A six-foot-wide hood exhausting 1200 cubic feet per minute, 24 hours per day, consumes more energy than an average house.

The most common energy-efficient modifications to traditional fume hoods are based on use of outside air (auxiliary air) or variable air volume (VAV) control techniques. While these approaches can save energy, they are complicated and costly to implement and operate, and do not address the worker safety issues inherent in the traditional fume hood design.

Innovation is hampered by various barriers stemming from existing fume hood testing/rating procedures, entrenched industry practices, and ambiguous and contradictory guidance on safe levels of airflow. These conditions make this technology area ripe for public interest research and development aimed at introducing innovative alternatives to current practice.

Containment Innovation

To address the shortcomings of existing approaches and to promote innovation in the marketplace, Lawrence Berkeley National Laboratory has developed and patented a promising new technology—The Berkeley Hood—that reduces the hood's airflow requirements by up to 70 percent while enhancing worker safety by supplying most of the exhaust air between the hood's operator and the work area.

The LBNL containment technology uses a "push-pull" displacement airflow approach to contain fumes and move air through a hood (Figure ES-3). Displacement air "push" is introduced with supply vents near the top and bottom of a hood's sash opening. Displacement air "pull" is provided by simultaneously exhausting air from the back and top of the hood. These low-velocity airflows create an "air divider" between an operator and a hood's contents that separates and distributes airflow at the sash opening (unlike an air curtain approach that uses high-velocity airflow). When the face of a hood is protected by an air flow with low turbulent intensity, the need to exhaust large amounts of air from the hood is largely reduced. The air divider technology is simple, protects the operator, and delivers dramatic cost reductions in a facility's construction and operation.

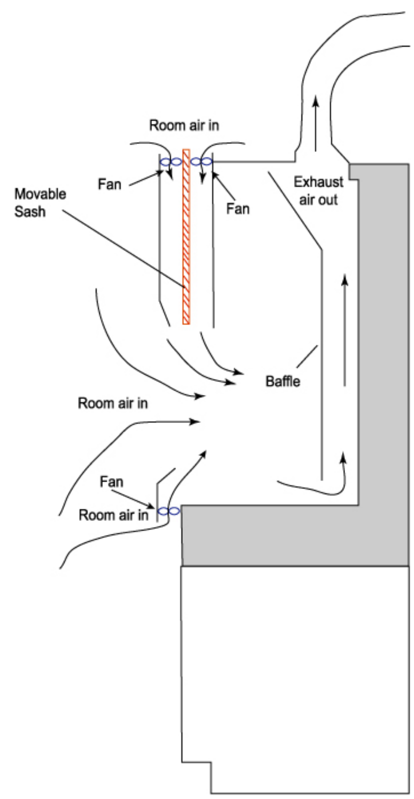

Figure ES-3 Schematic of the high-performance Berkeley Hood; sectional view shows airflow patterns.

The Berkeley Hood attains greater containment and exhaust efficiency, resulting in an effective and energy-efficient solution (Figure ES-4).

An added attraction of the Berkeley Hood is that it is expected to be less expensive than VAV fume hood systems. Savings from downsized heating, ventilating, and air conditioning systems will, in most cases, offset any first-cost premium of the Berkeley Hood.

The project team has developed several “alpha” prototypes of the Berkeley Hood for laboratory applications (Fig ES-5). LBNL is collaborating with various industrial partners to refine and apply the technology in research laboratories and microelectronics applications.

Figure ES-4. High-performance Berkeley Hood, showing full pollutant containment during flow-visualization test.

Field Trials Validate Performance

The University of California, at San Francisco (UCSF) field test has increased our understanding of operability of the Berkeley Hood under actual working conditions in a functioning laboratory.

At UC San Francisco, the Berkeley Hood has performed quite well in some cases exceeded expectations (Table ES-1), containing test smoke and tracer gas under all conditions down to 33 percent of full flow. Notably, the pre-existing standard hood failed certain tests for containment, even at full flow.

Figure ES-5. Labconco alpha prototype Berkeley Hood.

Post-Occupancy Evaluation

We conducted a post-occupancy evaluation of the UCSF demonstration, based on interviews with the hood user, a twenty-year veteran lab manager. The overall appraisal was excellent. Installation posed no undue inconvenience and had no adverse effects on the performance of hood-related tasks. The user saw no ways of making the hood more convenient or need for additional features. The adjustment from the old (standard) hood to the Berkeley Hood was “seamless” and did not require any special training. When asked if design changes were called for, none were identified.

Table ES-1. ASHRAE 110 Test results for Labconco unit at UC San Francisco.

Test Type	*Test Conditions*	*Air Flow % of "normal" (100 fpm)*	*Berkeley Hood Containment AM (as mf'd)*	*Berkeley Hood Containment AI (as installed)*	*Berkeley Hood Containment AU (as used)*	*Standard (Existing.) Hood Containment @ 100 FPM*
Smoke	Small volume Smoke tube	50%	Good	Good	Good	Fair
Face Velocity [a]	Sash Full Open	50%	N/A	N/A	N/A	Fail
Tracer gas [b]	Sash Full Open; three positions	50%	Pass	Pass	Pass	Fail [c]
Tracer gas [b]	Sash movement; three positions	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Safety margin check	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; Three positions; breathing zone @ 18 inches	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash movement; three positions; breathing zone @ 18 inches	50%	Pass	Pass	N/A	N/A
Tracer gas [b]	Sash full open; breathing zone @ 18 inches	40%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; breathing zone @ 18 inches	33%	Fail	Fail	Fail	N/A

a. Face velocity Pass/Fail criterion per CAL/OSHA 5154.1.

b. Tracer gas Pass/Fail criterion per ANSI Z9.5 1992.

c. Fail criterion per NIH (1996); marginal pass per ANSI Z9.5 1992.

N/A = not applicable or not done

Widespread Benefits

When cutting airflow by up to 70 percent in standard laboratory fume hood installations, we estimate that California laboratories could save 360 to 720 Gigawatt-hours (GWh) of electricity annually, and 100 to 200 megawatts of electrical peak generating capacity. This energy savings equates to about $41 to $82 million per year, or $1,000/year/hood, with higher savings likely in most other U.S. climates. Nationwide, total annual savings are estimated to be $240-480 million,[1] corresponding to 2,100 to 4,200 GWh annual electricity production and 600 to 1,200 GW of peak electrical capacity.

Beyond ventilation reduction and associated energy savings, the Berkeley Hood offers design features that deliver a range of benefits:

- Simpler design than state-of-the-art variable air volume (VAV) fume hood systems offers more certain energy savings, coupled with easier and less

[1] These estimates predate the energy crisis of 2001, at which time prevailing energy prices were three to four times higher in some areas than those used in this analysis ($0.08/kWh for electricity and $120/kW demand charges).

expensive installations and maintenance.

- Constant volume operation ensures energy savings are independent of operator interface.
- Improved containment reduces dangerous airflow patterns, eddy currents, and vortexes.
- Clean room air flowing, into the operator's breathing zone reduces potential hazard from fumes.

In new construction projects, designers specifying the Berkeley Hood can achieve savings in energy, construction, and maintenance costs. While the Berkeley Hood itself is expected to have a direct first-cost premium over a current standard hood, this cost can be offset with first-cost savings from smaller ducts, fans, and central plants, as well as simpler control systems for VAV, offering lower overall first cost than standard or VAV hood systems.

In retrofit projects, Berkeley Hood users can receive critical HVAC system benefits beyond energy savings. Many laboratories are "starved" for air as their need for hoods has grown over the years. As a result, low supply or exhaust airflows cause inadequate exhaust, in some cases, potentially leading to contaminant spills from the hood. Since increasing supply airflow is very costly in most cases, many laboratories cannot add new hoods. By replacing existing hoods with Berkeley Hoods, users can increase the number of hoods or improve exhaust performance, or both. The final result is improved research productivity, enhanced safety, and lower energy bills.

Project Supporters

Although PG&E provided funding for this field test, additional funding and other forms of support have been provided by the following organizations to address various closely related aspects of the hood's development and testing:

- *U.S. Department of Energy*… Multi-year funding for hood development and to develop intellectual property.
- *California Institute for Energy Efficiency (CIEE)*… 1998 to 1999 for technology development and technology transfer.

The following organizations provided in-kind support:

- *Labconco*… Provided a fume hood superstructure for modification and use in prototype development. Built prototype for demonstration installation and field testing.
- *Fisher-Nickel/PG&E Food Service Technology Center (FSTC)…* Collaborated by sharing ideas and methods to visualize air flow in hoods. Used FSTC schlieren device to study Berkeley Hood airflow patterns. LBNL presented at conferences sponsored by FSTC to demonstrate

airflow visualization techniques.

- *Siemens Building Technologies and Controls*… Provided monitoring and control equipment and expertise for field test.
- *US Filter/Johnson Screens…* Provided protective grill for lower plenum supply at reduced cost; worked with LBNL to design and fabricate special grill.
- *University of California at San Francisco…* Provided site and funded installation for the first California demonstration of the Berkeley Hood.

The following organizations served as consultants to the project:

- *Exposure Control Technologies…* Provided expert review and evaluation of Berkeley Hood at LBNL.
- Knutson Ventilation… Provided expert review and evaluation of Berkeley Hood at LBNL.
- *Marina Medical Mechanical…* Installed the Berkeley Hood at UCSF Medical Center in San Francisco.
- *SafeLab Corporation…* Provided expert review and evaluation of Berkeley Hood at LBNL.

* * *

The project web site (http://ateam.lbl.gov/hightech/fumehood/fhood.html) includes additional project information, including detailed supporting documents, videos demonstrating containment, and current/upcoming project activities.

BACKGROUND

Historical Laboratory Fume Hood Development

The earliest fume hoods were used over open fires inside buildings, e.g. at smith’s forges. They provided containment with thermal updrafts in tall chimneys, which resulted from rising air made buoyant by the fire. During the Industrial Revolution, gas-burning rings used to increased drafts were replaced by mechanical fans. The next major improvements were the introduction of a five-sided “box” with an operable sash that protected workers by varying the opening size. Later, a baffle system was added at the back of the box. The baffle helped to exhaust air from the hood's working surface area as well as from the top canopy area (Saunders 1993).

In the 1940s, the Atomic Energy Commission asked the Harvard School of Public Health to develop equipment for improving hood operation and safety. As a result, the School improved fume hood entrances to streamline air flow patterns. The advent of High Efficiency Particulate Arrestors (HEPA) filters also resulted from this work. One industry source notes that, despite the claims of hood manufacturers, the basic hood design has changed little over the past 60 years(Saunders 1993).

In today's world, laboratory fume hoods are widely used in laboratories and other "high-tech" facilities such as cleanrooms. Varying estimates place the existing stock of fume hoods between 0.5 and 1.5 million. Fume hoods protect operators from breathing harmful fumes by capturing, containing, and exhausting hazardous airborne material created in laboratory experiments or industrial processes. These box-like structures, often mounted at tabletop level, offer users protection with a movable sash that varies the opening size. Exhaust fans draw fumes out the top of each hood by inducing airflow through the front opening, or face, of the fume hood.

Hood airflow face velocity through the sash was originally considered adequate at 50 feet-per-minute (fpm, or 0.25 meters per second, m/s). However, this value increased over time to 150 fpm (0.75 m/s) to "improve" hood safety. Only when a research project, sponsored by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), produced a procedure for establishing fume hood performance were face velocities reduced to the range of 60 to 100 fpm (0.3 to 0.5 m/s) (Caplan and Knutson 1978a). This research—based on new information relevant to worker safety—formed the basis of ASHRAE Standard 110-1985, a standardized method for evaluating laboratory fume hood performance.

Current Technology

Standard Designs Dictate High Exhaust Rates

Standard fume hood design (Figure 1) is based on air flows of 100 feet per minute and the assumption that the sash is fully open. Therefore a hood with a standard 5-foot by 2.5-foot opening requires an exhaust rate of 1250 cubic-feet-per-minute.

Figure 1. Standard laboratory hood in use.

Contrary to common expectations, increasing face velocity does not improve containment. Instead, errant eddy currents and vortexes are induced around hood users as air flows into the hood, reducing containment effectiveness.

Laboratory fume hoods are operated 24 hours/day. Since many laboratories have multiple hoods, they typically dictate a lab's overall required airflow and thus the entire facility's supply and exhaust system capacity (and thus cost). The result is larger fans, chillers, boilers and ducts compared to systems having less exhaust. Consequently, fume hoods are a major factor in making a typical laboratory four- to five-times more energy intensive than a typical commercial space.

Currently Available Energy-Efficient Systems Face Limitations

In the past, four design strategies have been used to reduce fume hood energy use.

- ***Using "auxiliary" (outside) air to reduce energy required by a central HVAC system that conditions the air ultimately exhausted by the hood.***

This strategy, referred to as an auxiliary-air hood, introduces outdoor air near the face of the hood just above the worker. Un-conditioned air introduced by auxiliary-air hood systems causes uncomfortable conditions for workers during periods of summer and winter temperature or humidity extremes. The auxiliary airflow can interfere, in various ways, with experiments performed inside the hood. More importantly, turbulence, caused by inflowing auxiliary air at the hood opening, increases the potential for pollutants to spill from the hood towards the worker (Coggan 1997; Feustel et al. 2001). Moreover, auxiliary air hoods only save energy used for conditioning general laboratory air. This is the case because total exhaust flow rate is unchanged. A hood's fan energy consumption is not reduced and may even be increased by the necessity of an auxiliary supply fan. Our estimates indicate that as much as 65 percent of hood energy is attributable to the fans (moving air) with the balance attributable to conditioning the air.

- ***Employing dampers and adjusting fan speed to reduce exhaust airflow through the hood as the sash is closed. This variable air volume (VAV) approach maintains a constant face velocity, enhancing the hood's ability to contain fumes.***

This strategy dampers, variable speed drives (VSDs), and sophisticated controls to modulate the hood and in the supply and exhaust air streams. These components communicate with direct digital controls (DDC) to provide a variable air volume (VAV) fume hood system. A VAV system establishes a constant face velocity. VAV improves safety, compared to standard hoods, which experience variable face velocity as the face is adjusted. Additional controls maintain a constant pressure differential between the laboratory and adjacent spaces. These components and controls add significantly to the system's first cost and complexity and require diligent users. Each hood user must operate the sash properly to ensure that the system achieves its full energy savings potential. Also, when sizing air distribution and conditioning equipment, many designers assume worst-case conditions—all sashes fully open—requiring larger ducts, fans, and central plants than would be the case if some sashes were assumed to be partly closed.[2]

- ***Restricting sash openings by preventing the sash from being fully opened, or using horizontal-sliding sashes that cover part of the hood entryway even when in the open position.***

This strategy restricts a hood's face opening while maintaining air flow velocity. The face opening is restricted by limiting vertical sash movement with "stops" or using a horizontal sash system that blocks part of the entrance even when fully open. Generally, the stops or sashes are removed by users to facilitate "set-up" of experiments. During set-up, the face velocity is lowered, often significantly, and containment reduced. Users often do not like these restrictions, so it is common to see hoods under normal use with their stops bypassed or the horizontal sashes removed. In these cases, the air velocity drops below specified levels and compromises safety.

- ***Automated designs that promote a vortex in the top of the fume hood, which is maintained by "sensing" whether it is collapsing, or not, and adjusting movable panels in the top of the hood accordingly.***

This strategy has been effectively applied to fume hood design, although it is not entirely accepted or understood by laboratory designers. This hood design incorporates, according to the manufacturer, a "bi-stable vortex" to enhance its containment performance. The design promotes a vortex in the top of the fume hood, and maintains this vortex by "sensing" whether it is collapsing, or not, and adjusts movable panels in the top of the hood accordingly.

[2] Based on the assumption that not all hoods are used simultaneously in a VAV fume hood system, applying a "hood diversity factor" in calculating the building's make-up air has also been suggested as an HVAC energy-saving measure (Moyer and Dungan 1987; Varley 1993). For safety reasons, we do not suggest switching off hoods.

Opportunity For Improvement

A New Approach to Containment and Safety – The Berkeley Hood

Conventional hoods (and the above-mentioned energy efficiency strategies) rely on pulling supply air from the general laboratory space around the worker and research apparatus that may be located in the hood. Safety performance is susceptible to everyday activities in the lab, movement of people, opening and closing of doors, central air supply fluctuations, etc. Past efforts have not looked at the potential for re-conceptualizing and redesigning the hood to maintain or improve worker safety with lower air flows.

A new strategy for managing fume hood energy, the Berkeley Hood technique supplies air *in front* of the operator, while drawing only about 10 to 30 percent of the air from around the operator (Bell et al. 2001).[3] As a result, far lower flow-rates are necessary in order to contain pollutants and flow-rates remain virtually unaffected by adjustments to the sash opening. This supplied air creates a protective layer of fresh air free of contaminants. Even temporary mixing between air in the face of the fume hood and room air, which could result from pressure fluctuations in the laboratory, will keep contaminants contained within the hood.

The Berkeley Hood uses a "push-pull" displacement airflow approach to contain fumes and move air through a hood. Displacement air “push” is introduced with supply vents near the top and bottom of the hood’s sash opening. Displacement air “pull” is provided by simultaneously exhausting air from the back and top of the hood. The low-velocity supply airflows create an “air divider” between an operator and a hood’s contents that separates and distributes airflow at the sash opening (unlike an air curtain approach that uses high-velocity airflow). When the face of a hood is protected by an air flow with low turbulent intensity, the need to exhaust large amounts of air from the hood is largely reduced. The air divider technology contains fumes simply, protects the operator, and delivers dramatic cost reductions in a facility’s construction and operation.

The Berkeley Hood must not be confused with the auxiliary air approach. There are fundamental and material differences, stemming from the fact that the Berkeley Hood does not utilize outside air, and that air is introduced from within the sash in a highly controlled fashion with far lower turbulence (and thus lower risk of contaminant spillage) than occurs with auxiliary hoods. In auxiliary-air hoods, turbulent airflows coming from above the worker in auxiliary-air systems increase mixing of incoming fresh air and contaminated air within a hood’s workspace.

An added attraction of the Berkeley Hood installation is that its incremental cost is expected to be less than that of VAV systems. Savings from downsized heating, ventilating, and air conditioning systems and less complicated controls would also be realized.

[3] This generic concept was first tested in the “air vest” technology, invented at LBNL for use with large paint spray hoods (Gadgil et al. 1992). The vest supplies air in front of the operator of the hood, which creates a positive pressure field that prevents development of a wake, therefore ensuring clean air to the operator’s breathing zone.

Initial Groundwork

LBNL developed basic concepts for a high-performance laboratory fume hood during 1995–1998 (Feustel et al. 2001).[4] This early work included a number of activities, including:

- Establishing proof of concept by fabricating and testing hood mock-ups.
- Conducting simple, two-dimensional computational fluid dynamic (CFD) analysis to determine airflow patterns in standard hood configurations.
- Presenting preliminary results to industry groups and soliciting support.
- Publishing findings.
- Obtaining patents.

Market Analysis

The project team conducted a preliminary analysis to identify market size, potential energy savings (Table 1, below), and potential market impact. The results suggest the following:

- Approximately 150,000 laboratories populate the United States
- We estimate that between 500,000 and 1,000,000 fume hoods are installed in the United States, of which 85,000 to 170,000 are in California. While we have seen estimates as high as 1.5 million, we have conservatively chosen a narrower range for the purposes of estimating energy savings.
- Each new hood will save about 2.3 kW and 8.5 MWh/year (based on a relatively small five-foot hood opening and mild California weather conditions; savings will be greater in other climates).
- Approximately 50 percent of all existing hoods could be replaced with the Berkeley Hood, with total annual California electricity savings of 360 to 720 GWh and 100 to 200 megawatts of electrical generating capacity. Inclusion of space-heating (largely non-electric) would increase the total energy savings.

Further work is required to refine the engineering assumptions as well as the data on stock characteristics. Existing estimates of hood populations vary widely. The energy performance and savings potential of fume hoods is highly dependent on regional weather conditions, baseline HVAC system efficiencies, and market penetration of substitute technologies.

[4] Dr. Feustel left LBNL in January 1999. At that time, LBNL's Environmental Energy Technologies Division (EETD) transferred the project to its Applications Team, with Dale Sartor, P.E. as Principal Investigator and Geoffrey C. Bell, P.E. as Project Head. Dr. Feustel remains a consultant to the project.

Table 1. Analysis of fume hood national electricity savings potential.

Assumptions	
Average hood flow rate	1,250 cubic feet per minute (cfm)
US hoods	500,000 to 1,000,000
California hoods	85,000 to 170,000
Maximum replacement potential	50% of all existing units
Air flow supply & exhaust system fan energy	1 W/cfm (much higher at margin in retrofit)
Chiller plant energy	1 kW/ton
Cooling peak delta T	30 degrees F
Average cooling delta T	20% of peak (i.e., 6 degrees F)
Cost per kWh	$0.08
Cost per kW	$120/year
Per-hood savings	50% (75% for hood, but assumes minimum general lab exhaust overrides)
Calculations	
Cooling peak tons/hood	3.44 (1250 cfm * 1.08 BTU/h/ft^3/minute/degree F * 30 degrees delta-T / 12,000 BTU/hour/degree F)
Cooling peak kW/hood	3.44
Air flow kW/hood	1.25
Total peak kW/hood	4.69
Cooling kWh/hood	6,023 (8760 hrs * 3.44 kW/hood * 20%)
Air flow kWh/hood	10,950 (8760 hrs * 1.25 airflow kW/hood)
Total kWh/hood	16,973
US energy use, peak demand, and annual cost	8.5-17 TWh / 2.3-4.6 GW / $1-2 billion
Calif. energy use, peak demand, and annual cost	1.4-2.8 TWh / 0.4 -0.8 GW / $0.2-0.4 billion
Annual savings kW/hood	2.34 ($281)
Annual savings kWh/hood	8,486 ($679)
Total annual savings/hood	$960
California peak power savings	0.1 to 0.2 GW
Annual California electricity savings	360 to 720 GWh
U.S peak power savings	0.6 to 1.2 GW
Annual U.S electricity savings	2,100 to 4,200 GWh
Annual cost savings ($M) – CA / US	$41 - $82M / $240 - $480M

Approximately 150,000 laboratories populate the United States, with 500,000 to 1,000,000 total fume hoods installed. This estimated range is based in part on interviews of industry experts conducted on behalf of the Labs21 project, and excludes an “outlier” estimate of 1.5 million. The only formally published estimate indicated that there were more than 1 million units in 1989 (Monsen 1989). Conservatively we estimate that each new hood will reduce peak electrical load about 2.3 kW and save 8.5 MWh/year (based on relatively small hoods with 5-foot openings). Further, we estimate that 50 percent of all existing hoods could be replaced with the Berkeley Hood (technical potential virtually 100 percent), with total annual U.S. electricity savings of 2,100 to 4,200 GWh (360 to 720 California) and 0.6 to 1.2 GW (0.1 to 0.2 GW in California). Note that our cost estimates (based on an electricity price of $0.08/kWh and $120/kW demand charges) predate the energy crisis of 2001, at which time prevailing energy prices were three- to four-times higher in some areas than those used in this analysis. Note: engineering analysis reflects California weather conditions. Usage (and savings) will be higher in many other regions.

Institutional Barriers

In conjunction with identifying design improvements and market opportunities, the project team pinpointed market barriers to adopting the new hood technology (Vogel 1999). Their research uncovered numerous hurdles to widespread adoption, including:

- The ASHRAE Standard 110-1995 is the most widely used test method for evaluating a hood's containment performance. This method recommends three types of tests but does not stipulate performance values that need to be attained by a fume hood. Aside from the ASHRAE method, the most commonly used indicator of hood capture and containment is hood face velocity. A commonly accepted value of 100 feet/minute (fpm) is widely applied. While this value has limited technical merit, it presents the most significant barrier to widespread adoption of the Berkeley Hood. Hoods using LBNL's low-flow technique provide containment of tracer gas and smoke per the other ASHRAE 110 tests but have an "equivalent" face velocity of approximately 30 to 50 FPM (with the internal supply fans off). The actual velocity is much less as most of the air is introduced at the face rather than pulled from outside the hood.

- In California, CAL/OSHA requires 100 fpm face velocity for a laboratory fume hood (non-carcinogen) to be in compliance, limiting the use of the Berkeley Hood in California and potentially in other States that follow California's lead.

- Other similar barriers can be found in a variety of standards. For example, the EPA promulgates a test standard that is used in their own procurement but is also adopted for use by others. The requirement for 100 fpm face velocity is deeply ingrained through this industry and will be a major market barrier to this new technology.

Research Efforts Expand

Based on early findings and successes, the project team developed a research plan with a comprehensive approach for developing the Berkeley Hood. The project worked with the California Institute for Energy Efficiency (CIEE) to verify the performance of the technique. The hood's ability to contain hazardous fumes was checked by an outside consultant by performing tests per a standardized protocol (ASHRAE 110, described below). This rudimentary prototype passed the containment tests, proving the merit of the technique (Feustel et al. 2001). Early CIEE funding was augmented with support from the DOE and Montana State University (MSU). This support, and the test results, encouraged Labconco to provide "in-kind" support by donating a four-foot-wide hood to the project. This combined support allowed research to expand significantly. The project subsequently increased research and moved into the field test and demonstration phase to provide "real world" feedback to the development team.

FIELD TESTS: ACTIVITIES AND ACCOMPLISHMENTS

This section summarizes project activities and accomplishments, with the information split into three categories: (1) project administration; (2) field tests; and (3) market development. A complete, detailed Project Timeline may be found in Appendix A.

Project Administration

The Berkeley Hood project is a multi-year, multi-phase research and technology development project effort. It has been widely supported, by public and private organizations alike, and has leveraged expertise within a number of groups within LBNL.

Project Supporters

Initial work was supported by LBNL's Environmental Energy Technologies Division. In 1998, the California Institute for Energy Efficiency (CIEE) began funding the hood research as part of a multi-year, multi-phase research project in the high-tech building area. The early scoping research on the topic was performed by LBNL (Mills et al. 1996; Bell et al. 1996). Additionally, the U.S. Department of Energy (DOE) and Montana State University funded basic research and prototype development from 1999 through 2001.

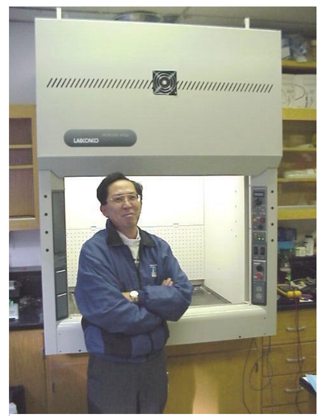

Figure 2. PG&E Rep. at Berkeley Hood.

In 2000, PG&E funded a field demonstration project with additional support from the test-site host, UC San Francisco. Figure 2 shows PG&E's representative, Stephen Fok in front of the demonstration Berkeley Hood at UCSF. Industry partners also supported this project, with participation from Labconco and Siemens Building Technologies.

Project Team

The project team leveraged expertise throughout LBNL's Environmental Energy Technologies Division (EETD). A team of student researchers greatly aided their efforts, particularly in fabricating and testing alternative hood features.

Summer Student Contributions

Soliciting candidates from The U.S. Department of Energy's Energy Research Laboratory Undergraduate Fellowship (ERULF) and Community College Initiative (CIC) Student Mentor Programs, LBNL hires students from various engineering disciplines from universities around the nation and abroad.

Once on board, the students faced a steep learning-curve to become familiar with laboratory fume hood technologies and to work productively in LBNL's environment.

Each researched fume hood technology and analyzed data. The students have made significant accomplishments in developing components and features for the prototype hood.

Field Testing

PG&E's Berkeley Hood field demonstration was installed and evaluated at the University of California, San Francisco Medical Center.

Prepare for Field Test

Establish Industrial Partnerships

Partnerships were established with research organizations, commercial hood manufacturers, and control companies. Industrial partners built an “alpha” prototype Berkeley Hoods used in the field test. The most current design information is transmitted to our partners on a regular basis.

Early Associations

A close association with PG&E’s Food Services Technology Center (FSTC) was formed early in the development process. This Center studies and evaluates commercial kitchen devices, including those that use exhaust hoods to remove waste heat and fumes. There is a great amount of similarity in the goals of a kitchen exhaust hood and a laboratory fume hood to remove unwanted air. A flow-visualization tool used at the FSTC, called a schlieren device. was borrowed by LBNL for testing the Berkeley Hood. A set up of the schlieren tool was completed at LBNL. We performed extensive evaluations of the Berkeley Hood, produced videos of test runs, and archived videos of the schlieren work on CD-roms.

Labconco became our first industrial partner. In May 1999, Labconco shipped a standard fume hood superstructure to LBNL. It was modified to become our first operational prototype. Containment was achieved in June 1999. Research and modifications continued until December 1999 when the design was provisionally “frozen.” An evaluation commenced to determine the hood’s performance envelope and to establish its operational safety.

Labconco provided industrial “muscle” to build the alpha generation of Berkeley Hood. This prototype was assembled in August 2000 and delivered to PG&E’s Pacific Energy Center the first week of September. At the Center, the hood was made operational and displayed for the *Laboratories for the 21st Century* conference attendees.

The hood was returned to LBNL for further tests and refinements prior to installation at UCSF.

Significant Support

Additional support from other industrial partners has provided significant insights and improvements to building a viable Berkeley Hood. These companies include: Siemens Controls, U.S. Filter/Johnson Screens, Technical Safety Services Company, ATMI, and Fisher-Hamilton. The field test sites made significant contributions. UCSF contracted for and funded mechanical and electrical system upgrades to accommodate the field test hood.

Study Safety and Containment Requirements

There is a certain level of confusion among industry professionals in applying fume hood safety standards, containment methods, and recommendations by "the authority having jurisdiction." Regulating authorities that have the "force of law" rarely agree on testing standards and regulating practices for fume hoods. Even experts can not always resolve conflicting recommendations and information provided by testing companies.

According to Uniform Building Code and Uniform Mechanical Code regulatory guidelines, laboratory fume hoods are primary environmental safety devices. Consequently, testing is necessary to ensure that fume hoods provide containment, which in turn means that workers are protected. The ASHRAE Guideline ANSI/ASHRAE 110-1995, *Method of Testing Performance of Laboratory Fume Hoods* is the foremost protocol used to perform laboratory fume tests. Additionally, to ensure safety, it is necessary to test each fume hood's efficacy on a continuing basis.

Perform ASHRAE 110 Tests

Test Preparations

Since the ASHRAE 110 Guideline is the most widely accepted method of testing fume hoods, a significant effort was made to prepare for conducting multiple ASHRAE-110 tests at LBNL. Initial steps included:

- Discussing with outside consultants to learn more about prior testing procedures on the original Berkeley Hood prototype.
- Contacting various companies concerning sulfur hexafluoride (SF_6) detectors, in an attempt to determine our best option for obtaining a detector.
- Collaborating with other LBNL staff members to complete the testing process.
- Pressure-testing the hood, ductwork, and plenums. Sealed all leaks possible with weather stripping and/or caulk.
- Preparing apparatus for testing—mounting brackets, mannequin height adjustments, velocity meter calibration, laboratory instrument placement representing real-world obstacles to airflow and containment.
- Participating in actual test runs and reducing data to leakage metrics.

ASHRAE 110 Test Basics

The ASHRAE-110 Method of Performance for Laboratory Fume Hoods is an elaborate, three-part test that involves face velocity testing, flow visualization, and a tracer gas test. These three main tests are outlined below:

- Face Velocity is a measure of the average velocity at which air is drawn through the face to the hood exhaust. It has been the cause of debates among standards committees. Regulating bodies do not agree on a specific number. For the most part, the accepted face velocity measure falls within an 80 to 100 fpm range. Some laboratories have accepted face velocities as low as 60 fpm (Ruys 1990). Despite their relatively low value in judging containment, face velocity tests are performed most often thanks to their low cost.

Figure3. Berkeley Hood, showing patented air-divider supply effect.

- Flow visualization tests can be performed with various smoke-generating substances (Figures 3 and 4). Theatrical smoke, superheated glycol, smoke "sticks", titanium tetrachloride, and dry ice (solid-phase CO_2) are examples of smoke sources. A qualitative understanding of containment is gained from conducting smoke tests. A rating system has been devised for "poor to good" patterns of smoke (Smith 2001). However, these tests are only used as indicators of containment. When satisfactory results are observed, they should be followed by tracer gas testing.

Figure 4. Berkeley Hood, showing full containment during flow-visualization test.

- Tracer gas testing is the most reliable method for determining a fume hood's containment performance. The gas most typically used is sulfur hexafluoride, or SF_6.[5] This gas flows into a fume hood being tested through a specially constructed "ejector" (Figure 5). The ASHRAE 110

[5] Gases are more likely to spill from a hood than are particulates. Thus, by inference, hoods passing this test will also adequately eliminate particles from the hood chamber.

guideline includes engineering drawings to fabricate this ejector. SF_6 flow rate is set at four liters per minute. The ejector is placed in different positions (center, left, and right) in the hood. A mannequin is placed in front of the hood being tested to simulate an operator. An inlet port to a detector device is placed at the "breathing zone" (the nose) of the mannequin. Tracer gas is allowed to flow for five minutes and spillage levels are recorded by the detector.

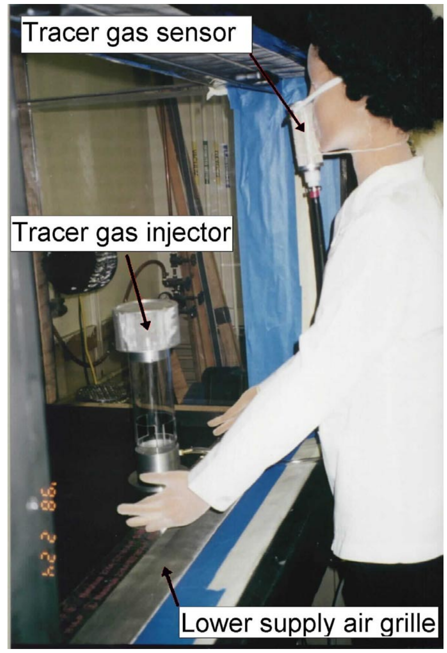

Figure 5. Setup for tracer gas test, with injector and mannequin in "right" position.

Ratings can be provided for a hood at three levels of installation:

- *"As manufactured"*—initial test of performance in a highly controlled/idealized setting commonly at the manufacturer's facility.
- *"As installed"*—testing is completed in the actual, fully operating facility, potentially more difficult conditions than the manufacturers' facility.
- *"As used"*—testing is performed by adding a hood operator's experimental equipment, a.k.a., "clutter", to the "as installed" hood, making the test conditions even more difficult.

ASHRAE 110 Test Limitations

The ASHRAE 110 procedure is a performance test method and does not constitute a performance specification. It is analogous to a method of chemical analysis, which prescribes how to analyze for a chemical constituent but, not how much of the substance should be present. Another analogy would be a method for measuring airflow; it prescribes how the flow should be measured, not how much volume it should be.

ASHRAE 110 is a series of the three aforementioned static tests; it only approximates the actual dynamic conditions of humans using a hood. For instance, the mannequin remains static throughout the entire testing procedure. At present, the mannequin's height is at one level. It has been demonstrated that as the mannequin's height is lowered, passing the 110 test may become more difficult. This is because a leak in the hood's lower level may not drift to the breathing zone (which is set at 26 inches [66 cm] above the work surface) of a 5'7" [170 cm] mannequin.

Once identified, limitations of the ASHRAE 110 method were discussed within LBNL. Communications with industry experts did not provide definitive resolutions. Although similar concerns are shared by industry experts, no consensus has yet developed.

However, developments in safety and containment evaluations and protocols are continuing.

Conducting a full three-step ASHRAE 110 test procedure is both time-consuming and expensive. Facility operators typically perform the 110 test only one time (if at all), at start-up, and conduct an annual face-velocity test thereafter. Testing requires complicated equipment such as purpose-built tracer gas ejectors, electron capture instrumentation, and mannequins (we found these to be surprisingly expensive). Highly trained technicians are required to operate the test apparatus and to evaluate a hood's performance.

LBNL is actively participating in the ASHRAE 110 committee to improve this test standard.

Summary of ASHRAE 110 Test Results

After conducting the research and prototype development described above, the project team demonstrated that the Berkeley Hood achieved containment levels equivalent to the majority of fume hoods "as manufactured," at exhaust flow reductions of 50 to 70 percent. Although no codes or standards provide performance criteria that categorically state a hood is "safe," the Berkeley Hood meets the ASHRAE Standard 110 Test with a containment rating of no greater than 4-AI-0.1 (4 liters/minute of SF_6, As-Installed, 0.1 ppm), suggested by ANSI/AIHA Z9.5-1992, *American National Standard for Laboratory Ventilation*. The hood achieved a leakage rate of only 0.01 to 0.02 ppm, far below the 0.1 ppm recommended maximum level noted by the American Council of Governmental Industrial Hygienists (ACGIH 1995).

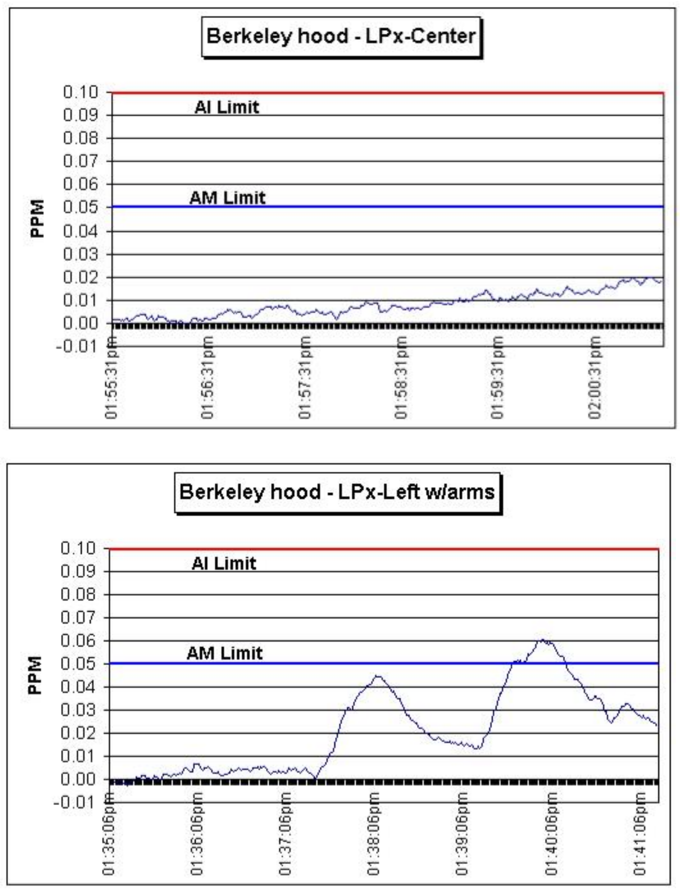

Figure 6. SF_6 tests at 40% of normal flow. A standard test (above) shows performance well within containment limits. A non-standard test (below) shows the impact of inserting the mannequin's hands into the hood. Note: upward trend is increase in SF_6 background, unrelated to hood performance.

Tracer-gas tests were performed on the final prototype before relaying specifications to Labconco for manufacture. The SF_6 detection was performed using a Foxboro Miran 1a, with the inlet tube located at the nose of the mannequin, at exhaust rates equal to 40% of those for standard hoods. In Figure 6, results are shown for standard test conditions and with insertion of the mannequin's arms into the hood (a more stringent requirement than that called for in the formal ASHRAE 110 tests).

Identify and Establish Demonstration Site

With support from PG&E, a field test project was initiated in March 2000. The project staff identified a field site at UC San Francisco's Medical Radiology Center in a pathology laboratory building. We began evaluating the site and potential installation challenges. Communication with UCSF facility personnel and the fume hood user began in April 2000. Fabrication and installation work began in late April and lasted until October 2000.

The UC San Francisco site was picked because campus personnel are highly regarded and had professional Environmental, Health, and Safety (EH&S) and facilities staff to assist with implementing the test.

A monitoring agreement was signed and received on 1 August 2000 from UCSF that allowed the field test to move to the next milestone of official UCSF permission to install the Berkeley Hood. Final permission was granted by UCSF on 13 October 2000 to actually schedule installation.

A kick-off meeting with UCSF personnel, our industrial partners, Labconco, Siemens Controls and UCSF's mechanical contractor, Marina Mechanical, was held at UCSF on 1 August 2000.

Benchmark Existing Hood Containment

Face velocity measurements on the existing hood ranged between 50 and 110 FPM (feet per minute) with an average of 89 FPM which normally indicates a hood that contains marginally well. However, one reading at 50 FPM would be cause to "fail" the hood. These readings were taken with the lab in its "normal" operating mode (as-used) which includes "clutter" in the hood, one missing ceiling tile, and an opened operable window. All of these items could contribute to the low 50 FPM face velocity reading.

Next, we performed the SF_6 tracer gas containment test. During the first "run" with the lab "as-installed", ASHRAE 110 values ranged from 0.01 ppm (parts per million) to 0.07 ppm (at 4 liters/minute gas flow). Depending upon the "standard" applied in an as-installed evaluation (NIH (1996) vs. ANSI Z9.5 1992), this hood failed. However, when the operable window was closed and the ceiling tile was replaced, containment improved to 0.01 ppm to 0.03 ppm; a marginal "passing" level for both NIH and ANSI.

The lab lacked room pressure control and, consequently, the air change rate was difficult to determine or maintain. For comfort reasons, occupants prefer to keep the windows open. Ideally, the window would be closed while the hood is in use and the hood sash closed at other times if the window is opened.

Design Improvements Based on Early Test Results

A prototype Berkeley Hood was delivered to LBNL in September 2000. It used a Labconco fume hood superstructure. It was highly customized by Labconco to accommodate installation of supply air systems and baffle modifications that are fundamental to LBNL's low-flow technique. However, this early version of the Berkeley Hood required modification and adjustments prior to installation at UCSF. Table 2 relates to the identified design/fabrication problems, their results influencing performance, and recommended solutions.

Figure 7. Labconco alpha prototype Berkeley Hood.

Install Prototype Hood

The Berkeley Hood became operational on 17 November 2000 (Figures 7 to 8). ASHRAE 110 testing by LBNL and Siemens Controls was performed on 5 December 2000. Flow deficiency was noted in the lower plenum, although the hood passed all ASHRAE 110 requirements. Evaluations and modifications were completed prior to Christmas 2000.

The installation included several novel features, including:

- A special Siemens control package that included alarms on the supply fans.
- An interface with the building exhaust fans to alert hood users if the fans failed.
- A purge feature with an override button that forces hood operation to full flow if the user encounters a spill or evidence that the hood is not containing the effluent.

Figure 8. Researcher working at Berkeley hood.

Installing the field test fume hood superstructure at the site required coordination beyond a normal hood installation. Engaging several construction trades and establishing interfaces with outside contractors were necessary including: facility metal shops, duct fabrication shops, electrical departments, facility EH&S departments, purchasing departments, and laboratory users. The installation process is depicted in Figures 9-17.

Table 2. Technical improvements to the Berkeley Hood.

Problem	*Results*	*Solution*	***Priority***
Lower plenum			H, M, L
Supply fan too close to plenum box	caused reverse flow into plenum due to high velocities near fan outlet	1. Added additional fan housing (without fan blades or motor) to provide longer run before fan flow enters plenum box 2. Added tape over first 2 inches of screen in plenum box.	H
Hole into plenum box too small compared to fan blade's outside diameter.	Reduced volume flow of fan greatly	Added additional fan housing (without fan blades or motor) to provide longer run before fan flow enters plenum box. (Hole could not be enlarged.)	M
Front Plenum			
Hole into plenum box too small compared to fan blade's outside diameter.	Reduced volume flow of fan greatly	Enlarged hole (Not addressed at this time).	M
Front cover of hood (with logo) blocks airflow to front plenum supply fan	Reduced volume of fan flow greatly	Provided different inlet hole to fan.	H
Screen does not seal properly on right side of hood.	Leaking screen upset air flow pattern into hood.	Adjusted plenum box to provide sealing surface.	H
Top Plenum			
Hole into plenum box too small compared to fan blade's outside diameter.	Reduced volume of fan flow greatly	Not addressed at this time.	M
Rear (Back) Baffle			
Top-most section of rear baffle does not extend into outlet slot.	Strong air flow behind baffle is not initiated thus reducing sweeping action at hood's counter top (work surface).	Fabricated new top baffle section	H
Top-most section of rear baffle needs to be set at an angle so 60 percent of air flow is behind baffle and 40 percent is in front.	Strong air flow behind baffle is not initiated, thus reducing sweeping action at hood's counter top (work surface).	Adjusted new top baffle section so that a 2 inch opening is in front of baffle with 3 inches behind.	H

The installation process required that we:

- Complete modifications and testing of prototype (at LBNL).
- Identify potential laboratory for hood installation.
- Coordinate installation with site's Environmental, Health, and Safety (EH&S) group and facilities department.
- Verify size and operation of existing exhaust fan.
- Select new exhaust fan as necessary.
- Determine exhaust duct routing for lowest cost.
- Size and pre-fabricate exhaust ductwork, including flow control and flow monitoring station.
- Coordinate install date with various trades and component suppliers.
- Clear and arrange laboratory space.
- Mount hood and seismically brace.
- Complete ductwork installation.
- Upgrade electrical service.
- Re-connect hood utilities.
- Mount control system for exhaust and supply fans.
- Calibrate exhaust air flow through hood.
- Commission hood.
- Document all phases with digital photos.

Figure 9. Ready to install

Figure 10. Rough install.

Figure 11. Exhaust duct connection.

Figure 12.Controls installed.

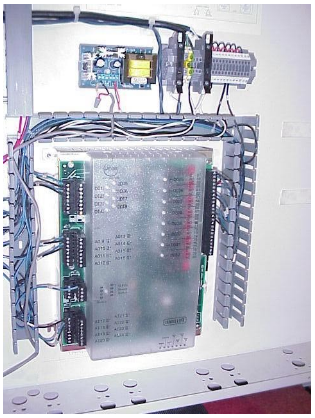

Figure 13. Control detail.

Figure 14. Hood utilities.

Figure 15. Lower supply grill detail.

Figure 16. Alarm Panel.

Figure 17. Installation complete.

Commission Hood

Once installed, the hood required modifications because of the project's customized and experimental nature. The team took special care to calibrate air flows and to install accurate measurement equipment.

Testing

The following containment tests were conducted:

Tracer gas testing

- Static test (section 7.1-7.9: ANSI/ASHRAE 110-1995) and as outlined in Subchapter 7 on General Industry Safety Orders.
- Peripheral test (section 7.11: ANSI/ASHRAE 110-1995)
- Sash Movement Test (section 7.12: ANSI/ASHRAE 110-1995)

Smoke visualization testing

- As outlined in Subchapter 7 on General Industry Safety Orders.

Two variables were recorded during tracer gas testing: Tracer gas concentration using a gas analyzer and duct exhaust flow using Siemens Building Technologies (SBT) control system.

The tracer gas concentration was recorded (Figures 18 to 23) using a dedicated data logging system while the duct flow was trended using Siemens Building Technologies control system.
Additional tracer gas tests were conducted including the following sequences:

- ♦ Loading of the fume hood
- ♦ Walking in front of the fume hood
- ♦ Door closing and opening

Test Results

On 05 December 2000 Siemens personnel thoroughly tested the hood with standard and non-standard ASHRAE 110 tests.

The hood was configured at 50 percent of normal flow based on 100 FPM (388 CFM). Testing began with a normal ASHRAE 110 static test which has the mannequin centered at 26 inches above the work surface, and the SF_6 ejector flowing at 4 liters per minute. The hood passed with a "flat line" reading, i.e., no evidence of spillage whatsoever. The mannequin was moved to the left side and right sides of the hood and tested (per standard ASHRAE 110 protocol), with no spillage resulting.

A non-standard test was performed next. The sash was moved up and down in each of these positions to perform the ASHRAE 110 "dynamic test". No spillage was detected.

Figure 18. Mannequin in center position.

Figure 19. Ejector in center position.

Figure 20. Hood with clutter, left view.

Figure 21. Hood with clutter, detail.

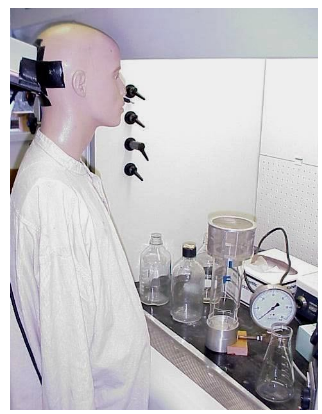

Figure 22. Hood with clutter, right view.

Figure 23. Data recording equipment.

The ITI Leakmeter was then moved around the perimeter of the sash, a Standard 110 test. No leakage was observed.

Next, the mannequin was lowered to 18 inches above the work surface and the testing agents performed both static and dynamic test runs, with no spillage observed.

Finally, the interior of the hood was "cluttered" with lab "equipment" to simulate an "as used" condition (Figures 18-23). With the mannequin at 18 inches above the work surface. No spillage was recorded. As a reference point during of the interval, checks were conducted to ensure the ITI Leakmeter was working by forcing SF_6 into the breathing zone or using a "cal bag" (a calibrated amount of SF_6 in a pouch).

After completing all of these test runs, it was considered instructive to make the hood fail by gradually lowering total exhaust volume (Table 3). The hood performed well down to 40 percent of normal flow; with the mannequin at 18 inches and the hood in an "as used" (with clutter) condition. Failure occurred at 33 percent of normal flow.

Table 3. ASHRAE 110 Test results for Labconco unit at UC San Francisco.

Test Type	*Test Conditions*	*Air Flow % of "normal" (100 fpm)*	*Berkeley Hood Containment AM (as mf'd)*	*Berkeley Hood Containment AI (as installed)*	*Berkeley Hood Containment AU (as used)*	*Standard (Existing.) Hood Containment @ 100 FPM*
Smoke	Small volume Smoke tube	50%	Good	Good	Good	Fair
Face Velocity [a]	Sash Full Open	50%	N/A	N/A	N/A	Fail
Tracer gas [b]	Sash Full Open; three positions	50%	Pass	Pass	Pass	Fail [c]
Tracer gas [b]	Sash movement; three positions	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Safety margin check	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; Three positions; breathing zone @ 18 inches	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash movement; three positions; breathing zone @ 18 inches	50%	Pass	Pass	N/A	N/A
Tracer gas [b]	Sash full open; breathing zone @ 18 inches	40%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; breathing zone @ 18 inches	33%	Fail	Fail	Fail	N/A

a. Face velocity Pass/Fail criterion per CAL/OSHA 5154.1.

b. Tracer gas Pass/Fail criterion per ANSI Z9.5 1992.

c. Fail criterion per NIH (1996); marginal pass per ANSI Z9.5 1992.

N/A = not applicable or not done

Post-Occupancy Evaluation

We conducted a post-occupancy evaluation of the UCSF demonstration, based on interviews with the hood user, a twenty-year veteran lab manager. The overall appraisal was excellent. Installation posed no undue inconvenience and had no adverse effects on the performance of hood-related tasks. The user saw no ways of making the hood more convenient or need for additional features. The adjustment from the old (standard) hood to the Berkeley Hood was "seamless" and did not require any special training. When asked if design changes were called for, none were identified.

Market Development

This section addresses the ultimate goal of the Fume Hood project, which is to see the technology through to commercialization and widespread deployment. Our approach follows five major pathways:

- Technology development and user evaluation
- Establish partnerships with hood manufacturers
- Identifying and overcoming market and regulatory barriers
- Outreach Activities
- Publicity

Within the technology development work—as described elsewhere in this report—we have implemented field tests, evaluated the installations, and collected user feedback. Experiences and lessons learned from the field test program lead to refinements in the hood's design and improved understanding of its operational envelope. An important first step in the field test program was to establish working partnerships with companies that have experience and industrial resources to assist research efforts. The market-barrier task identified several considerable issues. Outreach has been highly successful, and several important industrial partners have been identified, including some of the larger manufacturers of fume hoods, as well as other important trade allies (controls manufacturers, etc.). Two manufacturers have already manufactured prototype hoods. In support of our outreach efforts, we have seen a good level of publicity for the Berkeley Hood.

Identifying and Overcoming Market and Regulatory Barriers

Background

As noted above, the ASHRAE 110 guideline is a performance test method and does not constitute a safety rating. Therefore, organizations that issue standards and recommendations may supplement ASHRAE 110 by providing "target values" for tests results. These values are intended to indicate a hood's relative performance between safe and unsafe.

Two evaluation procedures in ASHRAE 110 are quantifiable and can be assigned target values to indicate a “safely” operating fume hood. They are the face velocity test, in feet per minute (FPM), and the tracer gas containment test, in parts per million (PPM) leak of SF_6 tracer gas when ejected at a particular rate inside the hood. Acceptable values for these tests are provided by various standards organizations.

Nearly all fume hood designs are tested by their manufacturers per the ASHRAE 110 Guideline. However, it is a very comprehensive test that can be time-consuming and expensive. To minimize testing cost and complexity, a facility typically performs only part of the ASHRAE 110 hood protocol, specifically face velocity tests. These face velocity tests are normally the sole basis that a facility uses to indicate a hood’s containment performance. Further entrenching face velocity as the only test for examining an installed hood is recurring (usually annual) testing. Most organizations can only afford to administer an annual face velocity test, thinking this is an adequate test for determining hood containment. (In many cases, a hood that passes a face-velocity test fails the tracer-gas test.)

Since ASHRAE 110 does not specifically stipulate what face velocity (in FPM) is “safe”, it is left up to “the authority having jurisdiction” to decide a face velocity that will provide operator safety. Most standards recommend an average face velocity “target value” of 100 FPM. Unlike standard fume hoods, the Berkeley Hood containment method decouples face velocity from safety performance. Consequently, recommendations of 100 FPM face velocity present the most significant implementation barrier to using the Berkeley Hood.

Uniform building, mechanical, and electrical codes; state and federal OSHA regulations; and Fire and Safety regulations (specifically NFPA) were studied with respect to laboratory “fume” hood installations. When adopted by local jurisdictions, these codes and regulations “carry the force of law.” Many regulations make reference to certain industry standards and guidelines. Potential barriers to using the Berkeley Hood were noted in these existing protocols and “standard” design guidelines (especially ASHRAE and ACGIH) (Vogel 1999; Fox 2000).

CAL/OSHA establishes standards for Californians that are often adopted by other States and jurisdictions. CAL/OSHA relies solely on an average face velocity of 100 FPM to indicate a “safely” operating hood. The current Berkeley Hood configuration has a equivalent face velocity of around 30 FPM (with internal supply fans off). Upon hearing this, most dismiss the Berkeley Hood as being unsafe, yet it has passed flow visualization and tracer gas tests that are far superior for determining containment and safety.

Transforming Barriers

A series of recommendations to nullify real and perceived barriers to using the Berkeley Hood are being compiled based on the hood’s advanced containment approach. Consequently, a new test protocol is being researched.

Crafting a new, widely-accepted test protocol will be a difficult process. Most testing programs conducted by a facility’s Environmental, Health, and Safety (EH&S) group, rely upon face velocity measurements to indicate a hood’s ability to contain hazards. These tests are performed on a regular basis, and therefore, a new test must be as simple to conduct and as repeatable. An SF_6 tracer gas test provides far more direct and compelling evidence that containment is being achieved, however, its high cost has precluded wide adoption.

Face Velocity Questioned

Reliance on face velocity testing as the sole method to assure a worker that their hood is containing fumes has been called into question in the past few years.

- A recent study by Dale Hitchings (1996), an industry consultant, noted that 59 percent of the hoods passed face velocity criteria. However, only 13 percent of those same hoods met tracer gas standards set by industry.
- Another report shows that 30 percent–50 percent of hoods leaking excessive levels of contaminants still pass the traditional face velocity tests (Hitchings and Maupins 1997). These failure rates have been confirmed by other fume hood testing experts (Knutson 2001; Smith 2001).
- In another study, an investigator found that in a properly designed laboratory, fume hoods with face velocities as low as 50 fpm provided "…protection factors…" 2,200-times greater than hoods with face velocities of 150 fpm (Caplan and Knutson 1978b).
- Another set of tests indicated that with the exception of one particular type of hood operation, there was no difference in hood containment with face velocities between 59 and 138 fpm (Ivany et al. 1989).
- At some laboratories, 60 fpm has been accepted (Saunders 1993).

Participate on Standards Committees

Participation on standards committees can help garner acceptance of the Berkeley Hood's high-performance air divider technique. Fundamental arguments regarding safety and containment capabilities of laboratory-type hoods need to be presented to committee members.

ASHRAE Activities

The ASHRAE Guideline ANSI/ASHRAE 110-1995, *Method of Testing Performance of Laboratory Fume Hoods* is revised on a ten-year cycle. The next revision is to be published in 2005. ASHRAE announced the formation of the committee (June 2000) to revise the guideline. Geoffrey Bell, of LBNL, has been appointed to this committee. The LBNL project team has offered to work in four specific areas of interest that will be eventually addressed by the full committee including:

- Specialty hoods
- Ejector design and flow rate
- Effect of turbulence intensity
- ASHRAE vs. other standards

CAL/OSHA Activities

CAL/OSHA was petitioned by private industry to amend their stance on requiring all hoods (except for those working with 13 known carcinogens) to have 100 FPM face velocity. In response, CAL/OSHA convened an advisory committee to the Standards Board to review and recommend changes proposed to their standard 5154.1 *Ventilation Requirements for Laboratory-Type Hood Operations*. Geoffrey Bell, of LBNL, is on this advisory committee.

LBNL staff are coordinating a subcommittee that is developing a "performance-based compliance specification". The specification is an attempt to build a performance-based standard while the existing standard can be considered a "prescriptive-based" standard. The approach is predicated upon acceptance of an "either, or" compliance doctrine, i.e., of a prescriptive or a performance hood evaluation methodology, by the whole committee.

The committee struggled with stipulating a "floor" face velocity. This struggle goes to the heart of the matter; Can CAL/OSHA establish a standard that helps workers be "safe" and not be prejudicial against some fume hood technologies?

Review Alternative Test Methods

LBNL's project team contacted several industrial hygienists, EH&S personnel, and other experts in the fields of fume hood testing and certification to help develop methods or recommendations for testing the Berkeley Hood. Many potential hood test procedures and methods were identified (Griffin 1999). The new hood tests were compared and evaluated. Empirical evaluations need to be conducted.

- User Tracer Gas Test—a variation of the ASHRAE 110 tracer gas test using a human subject instead of a mannequin. As in the original test procedure, all facets of the ASHRAE-110 tests are followed. This user tracer gas test was performed with a human subject standing in front of a hood making consistent, prescribed movements, such as extending both arms into the hood and pulling them back out in one motion every 30 seconds (Altemose et al. 1998).

- Air Monitoring Test—a very simple test, but may require several days to collect useful data. In this method a user wears an air-monitoring device in the breathing zone while working in the hood and the test staff evaluates contamination levels at various velocities.

- In-Use Testing Procedure—similar to the User Tracer Gas Test but using other vapors and detectors while hood operators conduct normal hood activities. SF_6 was used in the original study, but other vapors and detectors could be used. It was designed to assess fume hood performance during normal work activities. Escape of the "challenge" gas is measured in the operator's breathing zone by a direct reading instrument (Ivany and DiBerardinus 1989)

- Dioctylphthalate (DOP) Test—DOP is a part of the NSF 49 test for Biological Safety Cabinets (BSCs) used to stimulate particles of less than 3 microns in size. In BSCs, this test is performed to determine the integrity of supply and exhaust HEPA filters, filter housing, and filter mounting frames while the cabinet is operated at the nominal set point velocities. An aerosol in the form of generated particulates of dioctylphthalate (DOP) is required for leak-testing HEPA filters and their seals. A recent research study (Joao et al. 1997) suggests that a more quantitative approach, using the NSF 49 procedure, might lead to a better understanding of fume hood limitations, and help evaluate exposure to not only the fume hood worker, but those sharing the laboratory as well. The test proceeds in the following manner: A DOP aerosol generator operated at 20 psi is connected to a metal canister 7 inches in diameter. The canister's open top is covered with 1-inch-thick open-cell foam to allow a relatively even discharge of aerosol in the geometric center of the fume hood work zone, approximating an aerosol emitting from a large beaker in the hood where the outer edge of the vessel was 10 inches behind the sash. DOP is released at 150 L/min. An aerosol photometer is employed to detect aerosol escape from the face of the hood. At the fume hood's face opening, the photometer probe is passed from left to right across the plane of the face, one inch in front of the opening in 1-inch-wide rows from top to bottom and readings are recorded. At the face opening a concentration reference point is recorded 4 inches in the work zone in the center of the face opening.

- NIOSH Method 1500—a test using special air sampling pumps (e.g. SKC Model, Gillian, MSA Personnel Pump), a human subject, and NIOSH Method 1300 equipment. This is an expensive alternative to other methods noted here.

- Photo Ionization Detector (PID) Test—PIDs monitor the concentration of toxic gas. These units have many applications in industry, at utility companies, and by fire fighters. Additionally, environmental consultants use PIDs to detect small traces of toxic gas, monitor hazardous waste, inspect leaking underground storage tanks, and monitor personnel exposure.

- CO_2 Test—a simple test where a palm-sized CO_2 packet is placed inside the fume hood. As the CO_2 is emitted, an air monitoring device or wand is used to capture and record the amount of spillage. This test is ideal in terms of expense, time, and portability. This makes the test seem a very promising choice. However, the drawback to using CO_2 is the chance of producing erroneous values due to human CO_2 production and normal "background" fluctuations.

Based on this review, no test methods are clearly superior to the SF_6 tracer-gas technique were identified. However, it is important to keep in mind that instrumentation for detecting SF_6 could register other leaking refrigerants as a false positive. It is also notable that, as part of the CFC phase-out goals for 2010, SF_6 may no longer be available for use as a new tracer gas.

Outreach Activities

PG&E FSTC Demonstrations

In March 2000 to support PG&E's Food Service Technology Center (FSTC) in San Ramon, LBNL demonstrated a neutrally-buoyant bubble generator at the annual conference, sponsored by the FSTC. The team also delivered a presentation on the Berkeley Hood at the Flow Visualization Conference sponsored by FSTC on June 30, 2000 at the Pacific Energy Center in San Francisco.

Prototype Presentations

Numerous presentations and demonstrations have been performed at LBNL of the Berkeley Hood for organizations including: Pacific Gas & Electric (PG&E), Southern California Gas Company (SOCALGAS), San Diego Gas and Electric Co. (SDG&E), Southern California Edison (SCE), The U.S Department of Energy, California Energy Commission, Northwest Energy Efficiency Alliance, San Diego State University, UC Santa Cruz, UC Santa Barbara, GPR Planners, San Francisco Chronicle, Siemens Controls, Phoenix Controls, Technology Performance Group, and many others.

EPA/DOE Labs21 Conferences

The project team presented an overview of the Berkeley Hood Project to the Labs 21 Conference in San Francisco on September 7, 2000. The team demonstrated the hood at a PG&E-sponsored reception held at the conference. The demonstration, held at the Pacific Energy Center, was well attended by at least 75 laboratory professionals.

Publicity

A number of organizations have recognized the Berkeley Hood's importance and potential impact and have publicized it or otherwise recognized it. These include:

- *UniSci* – Daily University Science News; 18 Jan 2000; news article.
- *Laboratory Network.com*; News and Analysis web site; 25 Jan. 2000; article.
- *The Alchemist*, trade organization's web site; 27 Jan. 2000; news article.
- *The Daily Californian*, Sci-Tech section, 14 February 2000; newspaper and web article.
- *Daily University Science News*, January 18, 2000
- *E-Source Tech News* Vol. 1 Issue 1, 18 February 2000; article.
- *Advanced Manufacturing Technology Alert*; 18 Feb. 2000; news article.
- *DOE This Month*, March 2000; article.

- ATMI's advertisement in *Cleanrooms*, Vol. 14, No. 3, a trade journal, in the March 2000 issue.
- Patent Announcement in *Cleanrooms*, Vol. 14, No. 10, October 2000.
- *San Francisco Chronicle*, article on the front page of the Business Section, Sunday, 28 January 2001.
- *Consulting Specifying Engineer* (forthcoming).
- *FEMP Focus* (forthcoming)

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Finally, thanks to everyone at the UCSF Med. Center. Eugene Lau, head of UCSF's EH&S department, realized the engineering benefits of the Berkeley hood early in our project and remains a strong supporter of our continuing research. And special thanks to both Margaret Mayes for being such a patient and understanding client and to Dave Bohler, with UCSF Facilities Dept., for taking time from his busy schedule to see this project through.

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APPENDIX A. PG&E TECHNOLOGY AND MARKET DEVELOPMENT TIMELIINE

Technology Development

UCSF Demo Install

Feb 2000	Compiled Statement of Work (S.O.W) for site demo tasks for Dave Bohler review and UCSF approval.
23 Feb 2000	Performed low-flow hood demo for PG&E reps in preparation for UCSF site demo.
1 Mar 2000	Conducted demo for Dave Bohler and assoc. from UCSF at LBNL.
13 June 2000	Visited UCSF Med Center for site review and analysis.
July 2000	Finished AutoCAD installation drawings for hood ductwork.
1 Aug 2000	Met with mechanical contractor and control system supplier at UCSF Med Center to establish installation requirements.
1 Aug 2000	Performed containment-baseline test on existing lab hood at UCSF Med Center using ASHRAE 110 and ANSI Z9.5 protocols.
4 August 2000	Received installation bid from mechanical contractor and layout drawings from controls contractor.
4 August 2000	Established demo hood delivery schedule from Labconco.
30 Aug 2000	Conducted demo of low-flow hood at LBNL for UCSF EH&S director.
18 Sep 2000	Received Labconco demo hood from PEC demo (LABS21) at LBNL.
6 Oct 2000	Completed upgrades to Labconco hood.
13 Oct 2000	Obtained UCSF EH&S approval to proceed with hood demo project.
16 Oct 2000	Contract notice-to-proceed issued.
19 Oct 2000	Installation of Siemens controls begins at LBNL.
21 Oct 2000	Hood is shipped to Marina Mechanical shop for preparation to install at UCSF.
6 Nov 2000	Finish fabrication of electronic alarm circuits Complete ductwork and transition-piece fabrication Mobilize for hood installation
13 Nov 2000	Remove existing hood and store Install new hood, control valve, and duct work Finish controls installation at lab Perform functional start-up of hood system Begin commissioning hood installation
20 Nov 2000	Finish commissioning hood Verify all control functions (part of commissioning) Complete hood functional tests and operational adjustments
27 Nov 2000	Perform ASHRAE 110 tests

	Complete operator, facilities, and EH&S training Begin lab work in hood
4 Dec 2000	Visit from Siemens Controls (will perform tests on 5 Dec) Follow-up with operator to ensure satisfaction
5 Dec 2000	Hood fully operational Performed ASHRAE 110 tests and alternates and passed all including "as used."
11 Dec 2000	Operate hood and continue to interview operator Removed lower plenum supply to improve air flow.
12, 14, & 15 Dec 2000	Worked at LBNL to improve lower plenum design.
18 Dec 2000	Complete Interim Status Report covering accomplishments to date
19 Dec 2000	Re-installed updated lower plenum
18 Jan 2001	Visited hood with representatives from SDSU, next demo site.
30 Jan 2001	LBNL professional photographer takes shots of hood and operator at hood for record.
22 Feb 2001	Visited hood with Phoenix Controls personnel.

Pacific Energy Center (PEC)/LABS21 demo

30 Jun 2000	Visited Pacific Energy Center (PEC) to arrange demo set up.
4 Aug 2000	Additional site visit to PEC completed; resolved fan control and placement of hood; transition ductwork arranged and connection arrangement designed.
14 Aug 2000	Fabrication of duct transition piece at LBNL sheet metal shop finished.
August 2000	Labconco shipped base cabinet and counter top to PEC.
5 Sep 2000	High-performance demo hood arrives at PEC.
5 Sep 2000	Installed demo hood at PEC for LABS21 conference.
6 Sep 2000	Demo to LABS21 conference attendees performed with great success.
7 Sep 2000	Presentation at LABS21 conference an San Francisco on new High-Performance Fume Hood Technology

Test and evaluation conducted with schlieren device

27 Mar 2000	Borrowed schlieren device from PG&E FSTC.
31 Mar 2000	Set device up for visualizing flow through low-flow hood.
3 Apr 2000	Schlieren device operational.
April 2000	Videos recorded to study performance envelope.
28 Apr 2000	Returned schlieren device to PG&E FSTC.
May 2000	Converted digital videos into computer files for study and analyses.

Market Development

CAL/OSHA

February 2000	Participated on CAL/OSHA committee to develop new hood test evaluations for certification.
March 2000	Nominated as member of advisory committee for fume hood certification.
2 May, 25 July, 3 Oct, 28 Nov 2000, 23 Jan 2001	CAL/OSHA meetings.
December 2000	Drafted performance-criteria specification as alternate to prescriptive compliance method now used for fume hood approval; under review by full committee.

ASHRAE 110

September 2000	Approved Member of ASHRAE 110 committee to develop new revised laboratory hood test standard.
December 2000	Volunteered to participate in the following subcommittees: Specialty hoods, turbulence intensity, ASHRAE 110 vs. other standards, Ejector design.
February 2001	Assigned to be Point Person for Ejector Design Subcommittee.

Support to Food Services Technology Center

6 Mar 2000	Visited FSTC to observe schlieren setup and demo.
15 Mar 2000	Prepared for conference demo by LBNL of neutral-buoyant-bubble flow visualization tool at FSTC.
17 Mar 2000	Presented helium-bubble flow visualization tool at conference.
17 Apr 2000	Presented at PEC use of a variety of visualizations tools at FSTC conference.